AIR CONDITIONING

Pressurization

The gaseous nitrogen released from liquid storage for cooling purposes, as discussed below, serves also to pressurize the cabin. Various cabin pressurization schedules were investigated, each selected for study on the basis of its particular effect on the following "critical" criteria:

Nitrogen required for pressurization alone.
Cabin differential pressure.
Pilot comfort in descent.

Isobaric Schedule - Unpressurized ram operation from sea-level until 26,275 feet cabin altitude is reached, then cabin altitude remains isobaric at this 26,275 feet at all higher airplane altitudes. Cabin differential increases during climb, reaching 5 psi as the airplane arrives at maximum altitude. This system requires the minimum nitrogen for pressurization of any possible schedule, using 161 pounds on a mission flight consisting of 400 knot climb, 123 minute cruise, and 200 knot descent. (This compares to 202 pounds for the same flight using the constant rate of climb system below). During descent at 200 knots the maximum cabin rate of descent is only 3930 fpm. On a 400 knot descent the cabin rate of descent goes as high as 33,500 fpm; however, the more important rate of absolute pressure increase associated with this at the altitude concerned is exactly the same as the maximum encountered with the military-type schedule below, and involves less sustained time at high rate.

Job#89B00980R
Box#4 Folder 59

AIR CONDITIONING (Continued)

Pressurization (Continued)

Constant Cabin Rate of Climb Schedule - The cabin altitude changes at constant rates set by the pilot to carry the cabin from initial to final altitude in the exact time spans of the airplane's climb and descent. A cabin differential of 5 psi is reached at initial cruise altitude, and remains constant during cruise, resulting again in a 26,275 ft. cabin at maximum altitude. However, this system has the inherent peculiarity of requiring cabin differential to reach a high of 6 psi on the way to or from cruise altitude. It was selected for study as requiring the maximum pressurization nitrogen of any practical schedule, using 202 pounds for the mission flight noted above. Pilot comfort during descent, on the other hand, is by far the best of any possible system, as indicated by the cabin pressure rate changes of 1460 fpm during 200 knot descent and only 8070 fpm at 400 knots. The latter rate compares to the above noted 33,500 fpm maximum for the isobaric system, and to 21,200 fpm reached with the military-type system below.

Military-Type Schedule - Unpressurized ram operation from sea-level until 5,000 ft. cabin altitude is reached, then isobaric pressure is held at 5,000 ft. until cabin differential has built up to 5 psi, with constant 5 psi differential at all higher airplane altitudes (above 18,365 ft). Since the first two systems above spanned the mission flight nitrogen requirement from minimum to maximum, this more normal system's nitrogen usage

AIR CONDITIONING (Continued)

Pressurization (Continued)

Military-Type Schedule (Continued)

was investigated for descent only. Here the 200 knot descent nitrogen amounted to 33 pounds, compared to 12 pounds and 40 pounds on the isobaric and constant rate systems, respectively, for the same descent. 400 knot descent nitrogen was also calculated for this system, amounting to only 9 pounds. The main use made of this particular schedule, however, was in investigating the relative pilot comfort between it and the isobaric schedule, during the 400 knot descent ($3\frac{1}{4}$ minutes). On the military-type schedule, after leaving maximum cruise altitude at time zero, the pilot spends the first 125 seconds subjected to cabin descent rates varying from 0.85 up to 15.5 inches of mercury/minute, whereas, with the isobaric schedule no cabin change whatsoever occurs during this time span. For the remaining 70 seconds both of these schedules would follow the same rate curve (approaching 21 inches of mercury/minute at sea-level), except that at 20 seconds the pilot with the military-type system starts a half minute of reprieve at zero rate in his 5,000 ft. isobaric cabin, then returning to the high rate for the final 20 seconds. This comparison shows both systems to be relatively severe on the pilot, such that he should not attempt such a rapid descent unless blessed with exceptional ear and nasal passages, or in an emergency. Study of the exact rate curves vs. elapsed time would seem to give the isobaric system

AIR CONDITIONING (Continued)

Pressurization (Continued)

Military-Type Schedule (Continued)

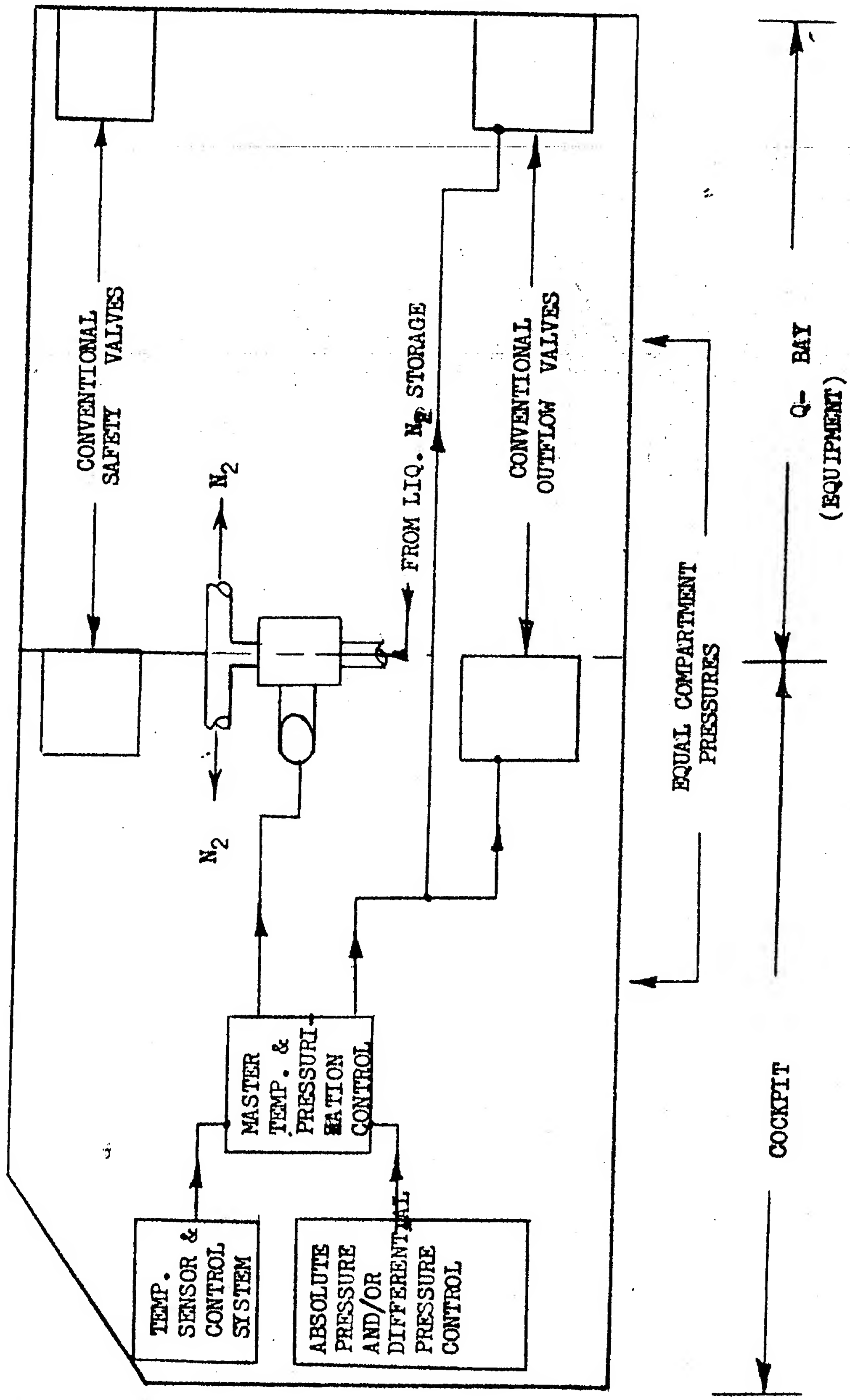
a slight edge over the military-type, on the basis of sustained times at high rate of change; this could probably be a point of argument between any two given pilots, however.

For the present, no attempt is being made to finalize the pressurization schedule, but merely to have at hand the information on which the discussions above were based. This is necessarily the case because of the inter-relationship between the nitrogen required for pressurization, and that required for cooling. It is felt that until final decision on the cooling system is reached, it will not be possible to give proper consideration to all factors for both systems.

Thus, no physical concept of the actual control components for pressurization can be stated at present; however, Figure 1 shows schematically a simplified general concept covering the inter-related controlling that must be accomplished. The master controller, whatever its form, must accept signals from both the temperature and the pressure sensors, and then influence both the outflow and the nitrogen flow valves accordingly. For example, with an increasing cooling requirement the master control must simultaneously increase the flow of cooling nitrogen, while opening the outflow valve to prevent over-pressure. Note that this example by itself

Lockheed AIRCRAFT CORPORATION
CALIFORNIA DIVISION

FIGURE 1



AIR CONDITIONING (Continued)

Pressurization (Continued)

Military-Type Schedule (Continued)

does not point up the necessity for such an inter-relating master control, since it is obviously quite a normal function of a pressure sensor to directly control its outflow valve towards open for such a case. However, reversing the example, assuming sufficient decrease in cooling-nitrogen inflow to drive a direct-controlled outflow valve fully closed, would result in depressurization. (The outflow valve by itself cannot "pump up" the cabin, being capable only of controlling a higher pressure generated at or beyond the point of cabin inflow. Note the dissimilarity between the more normal case of an "infinite" bleed air source available to a cabin, and the present "release it only as you need it" source). Now the need for the master becomes more evident, since it must recognize that even though temperature-wise the nitrogen flow can be reduced, it must still signal for nitrogen as an inflowing pressure source. (The temperature controller at this time will function only to position the recirculation bypass valve or valves).

For the latter condition of pressure-nitrogen requirement exceeding that for cooling, the outflow valve will close completely so that the only nitrogen flow will be that required for leakage make-up (plus or minus that involved in maintaining the contained weight of cabin atmosphere

AIR CONDITIONING (Continued)

Pressurization (Continued)

Military-Type Schedule (Continued)

during climb and descent). The "pressurization alone" values for nitrogen, quoted under the various schedules above, were calculated on this basis.

Note in Figure 1 that the series arrangement of outflow and safety valves gives double protection to the pilot against cockpit depressurization. For example, if the equipment bay were to depressurize for any reason the cockpit remains fully pressurized. As an alternate example, if the cockpit's outflow valve became stuck in the open position, the cockpit would again remain fully pressurized by riding on the equipment bay's valve. The probability of simultaneous-open failures is very low.

With the ram operation proposed for the unpressurized portions of the above described schedules, and the variable pressure source available during pressurization, it is considered that no negative pressure differential problem can normally exist, even during the 400 knot descent. In this regard calculations were made to determine the required variation between nitrogen flow rates for the 400 knot and 200 knot descents, to maintain full pressurization on the military-type schedule. This had been considered a possible problem on the fast descent from the standpoint of that nitrogen portion required just to increase the contained weight of cabin atmosphere. The results show, however, that even though the 400 knot descent time was faster by a factor of almost 6, its nitrogen

AIR CONDITIONING (Continued)

Pressurization (Continued)

Military-Type Schedule (Continued)

discharge rate (including leakage make-up) merely doubled. Further in regard to negative differentials, for the case of a nitrogen system failure during rapid descent, the outflow and safety valves will all be of the vacuum relief type and so sized as to prevent excessive structural loading.

Cooling

In the early stages of investigation, a look was taken at air-cycle ram cooling, with several variations of machinery and water boilers. As might be expected, the size and weight of the required equipment, plus material development problems due to the temperatures involved, eliminated this as a possible solution.

Engine bleed air was peremptorily eliminated for cabin use due to the airplane performance losses associated with bleed at our altitude. Note, however, that it is planned to use limited amounts of bleed air for windshield defogging and for ram air heating, if required, during the unpressurized portion of the pressurization schedules discussed above. The latter usage would become especially important were in-flight refueling to be considered, as here the normal time of ram operation would be far exceeded.

The most recent investigations have been aimed at accomplishing certain assumed design directives as follows:

AIR CONDITIONING (Continued)

Cooling (Continued)

> 100°F space temperature in the cockpit and equipment bay.
>
> 135°F maximum touch temperature of the trim in areas not directly over conductive structure, with minimum possible touch temperatures in all other areas.
>
> Cooling to be accomplished entirely by liquid media stored aboard the airplane (nitrogen, and possibly water).
>
> Cooling medium to double as cabin pressure source, as discussed above under pressurization.

The above temperatures take into account the fact that the pilot's comfort will be at the much more suitable level associated with direct suit ventilation by nitrogen gas, as on the X-15. This will include pilot-selected temperature controls.

One of the most attractive features of having aboard liquid nitrogen is the ease with which spot cooling of critical areas or equipment components can be accomplished. Thus such local areas are considered to be no problem.

A recirculation system was investigated on the basis of the above temperatures, wherein cabin atmosphere was cooled in two stages: first by passage through the air side of a water boiler, and then by injecting into it liquid nitrogen which topped-off the required cooling. This system was considered unattractive weight-wise at the time.

AIR CONDITIONING (Continued)

Cooling (Continued)

The most recent work, just completed, was a detailed study made of a water-panel system, for handling the major cooling load in those portions of the cabin wall between structural rings. Until the final stages of this investigation were reached, and the results could be integrated, this system looked extremely attractive. Regrettably, the final system weight has turned out to far exceed that of much less elaborate systems, even though as expected the amount of water expended was very small.

The studies made to date serve to indicate that the cooling problem, while severe, is not so extreme but that it is completely feasible to accomplish a practical system within the weight allowance set forth elsewhere in this report. This would be so even for a "nitrogen alone" system, and note in this regard that nitrogen's heat of vaporization amounts only to approximately a tenth that of water, at the pressures involved.

In ensuing investigations it is intended to exploit still further the advantages of using water's high heat of vaporization, in combination with top-off cooling by the "double-duty" pressurization nitrogen.

EMERGENCY ESCAPE

The A-11 will be provided with both low altitude and high altitude escape capability. Zero velocity escape systems will be carefully evaluated and used if feasible.

The pilot's seat will eject upward and will be provided with a rocket catapult.

This catapult assures adequate ejection clearance to the tail of the aircraft during all operating regimes. The long nose of the aircraft, which places the pilot far forward of the tail, and the low aspect ratio of the tail allow the man and the seat in an emergency ejection to clear the airplane tail with a considerable margin of safety.

The seat accommodates a suitable survival kit and bail-out oxygen system, and has a special shoulder harness and lap belt automatic release system.

Emergency ejection at the high altitudes and high speed at which the mission of the aircraft will be performed introduces new aspects to be considered in the problem of escape. The opening shock of the parachute, chute oscillation and the rotation of the pilot's body during free-fall must be retained within tolerable limits. The heat generated during ejection at cruise Mach number and deceleration of the man have been considered to insure that they are within body tolerances.

EMERGENCY ESCAPE (Continued)

Wind blast is a consideration during emergency ejection. The cruise Mach number, although high, corresponds to only 275 knots EAS. Maximum EAS to be used will be approximately 400 knots which occurs less than 15% of the flight time.

Wind blast effects and deceleration at these velocities are relatively low and safe ejections can be made within airspeeds with which we have had experience starting with the first jet fighters.

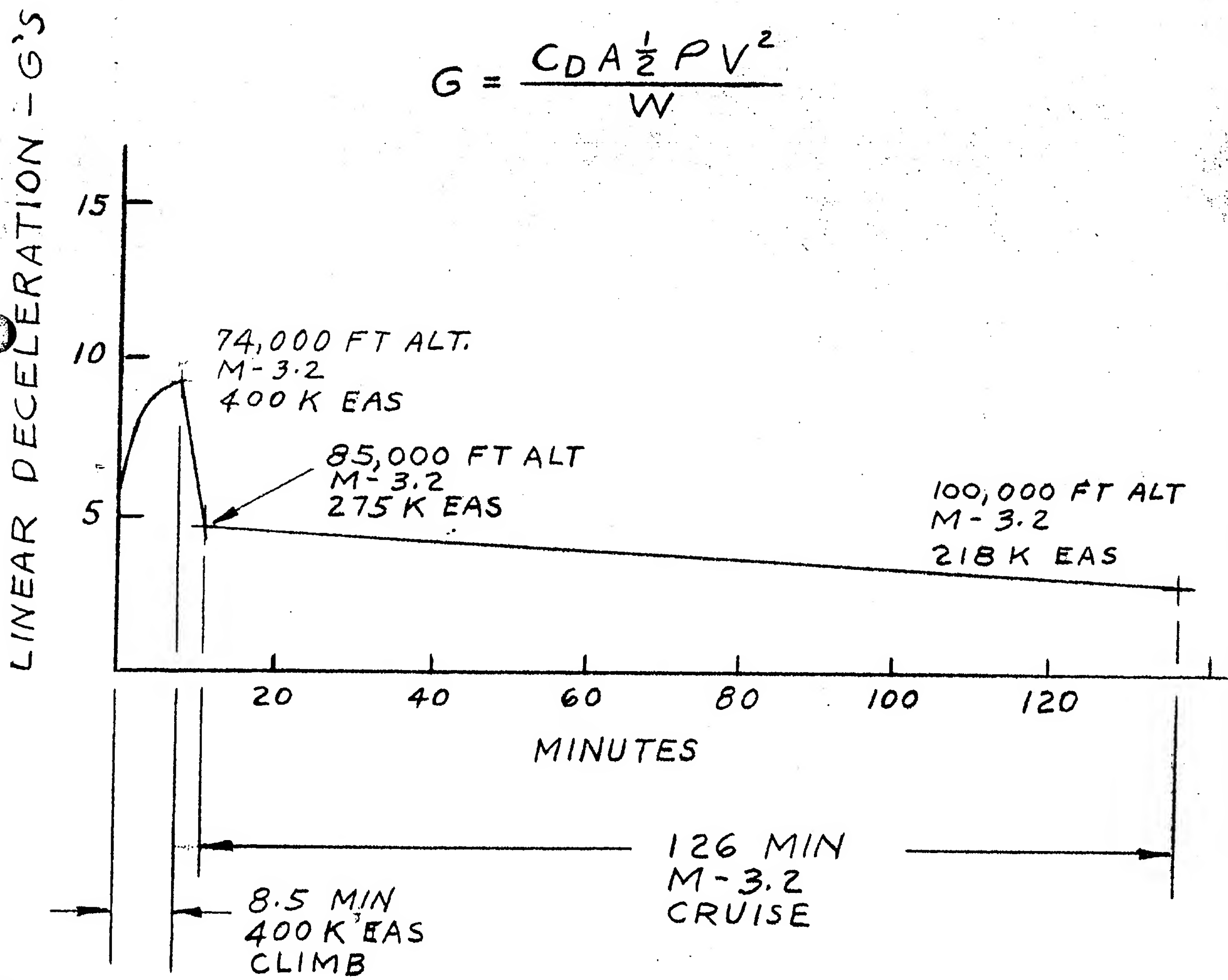
Heating of the man during ejection is not a serious problem. At 100,000 feet altitude, Mach 3.2 with the man in the seat, deceleration time is approximately 52 seconds. During this period the man and seat decelerate from Mach 3.2 to terminal falling velocity.

The initial ten seconds of this deceleration is the critical period so far as aerodynamic heating is concerned. After this ten seconds, the ejected pilot has slowed to approximately Mach 2.3 with a corresponding reduction in temperature. Some improvement of the temperature resistance of face pieces and pressure suit details is probably required to accommodate this transient condition.

It is proposed to use automatic seat belt and shoulder harness release of the type used in the F-104 to permit the pilot to remain in the seat until the initial deceleration is complete. This will reduce the hazard of pilot injury due to spin and tumbling, and prevent premature deployment of the primary chute.

EMERGENCY ESCAPE
MAN & SEAT DECELERATION
STABILIZED CONVENTIONAL SEAT

$$G = \frac{C_D A \frac{1}{2} \rho V^2}{W}$$



PERSONAL EQUIPMENT

In order to be compatible with the airplane and emergencies including escape, it is necessary to initiate a personal equipment development program for this particular airplane. The general nature of this program is to adapt and modify presently proven equipment and to develop a minimum of new equipment as required. A partial-pressure suit, such as used so successfully in the U-2 program is proposed as the basis for the pilot's wear.

The cockpit temperatures of 100°F require that the pilot be provided with some sort of a cooling and ventilation garment.

Lockheed understands that pressure suit development is being done at Edwards Air Force Base and proposes to make use of this program to provide the A-11 with the latest advance in full pressure or partial-pressure suits that the state of development permits.

A liquid oxygen system will be installed to provide oxygen for breathing and emergency suit pressure for the pilot.

To reduce the chances of system failure and interruption of oxygen flow to the pilot a dual system will be installed. Oxygen pressure failure, malfunction of system components, and loss of oxygen due to leaks will not abort the mission or endanger the pilot because the operative system can be isolated from the malfunctioning system.

PERSONAL EQUIPMENT (Continued)

The dual system design concept is included in the survival kit which contains the dual oxygen regulators. The dual oxygen regulators are joined together by a manifold valve which automatically accepts oxygen from the operative regulator when a regulator malfunctions, and blocks loss of pressure through the inoperative regulator.

The pilot also has a control valve on the survival kit to isolate the malfunctioning regulator. A pressure gauge is included to check the maintenance of oxygen pressure in the emergency bail-out bottle within the survival kit.

GENERAL

To obtain the maximum performance of the A-11 airplane, one of the available boron fuels will be used in the engines' afterburners. The superior heating value of boron fuels over hydrocarbon (26,500 Btu/lb. vs 18,400 Btu/lb.) will have a net result of approximately 12% overall increase in airplane range. A much greater increase of performance can be realized when the boron fuels can be burned in the main burners of the turbojet; however, since there has been only a limited amount of testing of boron fuels in turbojets, this will not be considered at this date. On the other hand, there have been highly successful runs made with boron fuels (HEF-2 and Hi Cal-3) on both afterburners and ramjets on test stands and with ramjets in flight on the Lockheed X-7 vehicle.

The A-11 airplane will carry approximately 31,000 pounds of boron fuel and 17,000 pounds of hydrocarbon fuel in separate tanks. This does not appreciably complicate the tankage problem as multiple tanks are required so an optimum airplane c.g. can be maintained during the mission by proper fuel scheduling from the various tanks. (See Figure 1 of "Structural Description" Section for c.g. location vs. time curve.)

It should be noted that the tendency of HEF fuels to cause high-altitude vapor trails is unknown at this time. Ground testing of this material results in large volumes of white vapor, but the dilution occuring in flight may reduce this to invisibility. A high speed, high altitude test in the X-7 would answer this question.

AIRPLANE FUEL SYSTEM

The A-11 airplane will carry 18,000 pounds of fuel in the wing tanks and 30,000 pounds of fuel in the fuselage. The bulk of the wing fuel will be JP-150; the small amount of HEF-3 in the wing will be burned before aerodynamic heating of the fuel becomes a problem.

The main HEF-3 tanks in the fuselage will be pressurized to approximately 8 psig. Of this, 2 psi will be used for fuel transfer and the remaining pressure will be used to prevent the fuel from boiling due to aerodynamic heating. This pressure will be maintained by dry nitrogen gas to insure an inert blanket over the HEF.. The nitrogen used will be carried aboard in liquid form to save the weight of high pressure bottles and also to serve as a heat sink for functional components.

Center of gravity control will be accomplished by scheduling the fuel from the various tanks as shown in Figure 1 of "Structural Description" section.

All tanks, fuselage and wing, will be integral with the structure. This saves considerable weight and gives maximum utilization of volume for fuel. The tanks will not be insulated; however, if aerodynamic heating of the fuel becomes a problem, it may be necessary to refrigerate the fuel prior to takeoff to insure adequate heat absorbing capacity.

BORON FUELS

There are several boron fuels currently being produced in limited quantities. By the end of 1959, Olin-Mathieson's and Callery's large plants will be "on stream", which will permit accelerated engine development and flight testing which has been hampered to date by the shortage of material. Olin-Mathieson Chemical Corporation will produce HEF-3, which is ethyldecaborane ($C_2 H_5 B_{10} H_{13}$). Callery Chemical will produce Hi Cal-III which is similar to ethyldecaborane $(C_2 H_4)_x B_{10} H_{14}$. Both of these fuels are relatively easy to handle and store as compared to the earlier boron fuels HEF-1 (pentaborane) and HEF-2 (propylpentaborane) which had many "nasty" characteristics and were difficult and dangerous to handle. The new fuels HEF-3 and Hi Cal-III are less toxic, have lower vapor pressure, are not pyrophoric, and are compatible with JP-150. Their thermal stability has been improved and their heating values are slightly higher. There is an increase in viscosity which will require somewhat more power to run pumps, but this is no major problem. Listed below are some of the properties of HEF-2 and HEF-3.

	HEF-2	HEF-3 Until 12-31-61
Thermal Stability a. Decomposition and solid formation	To be investigated.	Less than 1% decomposition by weight as evidenced by gas evolution and zero solid formation at the conditions listed below.

Time	Temp.
2 hrs.	350°F
1 hr.	390°F
30 min.	400°F
1 min.	500°F
15 sec.	570°F

BORON FUELS (CONT.)

	HEF-2	HEF-3 Until 12-31-61
b. Increase in viscosity		After being held for 30 min. at 400°F, the viscosity shall not have increased more than 2 cs at 77°F.
Heating Value (77°F) Refined as the reaction yielding Amorphous B_2O_3 and H_2 vapor	24,100 Btu/lb nom. 23,600 Btu/lb min.	25,800 Btu/lb. nominal 25,500 Btu/lb min. 26,200 Btu/lb max.
Specific Gravity (77°F)	0.70 nominal 0.65 minimum	0.82 nominal 0.80 minimum
Viscosity at 77°F	1.5 cs nominal 3.0 cs maximum	7 cs nominal 9 cs maximum
at -40°F	To be investigated.	150 cs maximum
Vapor Pressure 77°F	1.2 psia nominal 3.0 psia maximum	0.01 psia nominal maximum to be investigated.
Freezing Point	-76°F	-76°F
Spontaneous Ignition Temperature	Pyrophoric	260°F nominal 250°F minimum
Compatibility with JP-6 Fuel	Incompatible	Compatible under N_2 atmosphere
Storage Stability	Zero solids formed after 3 months storage in an inert atmosphere at temperatures in the range of -65°F to +160°F.	Zero solids formed after 6 months storage in an inert atmosphere at temperatures in the range of -65°F to +160°F.
Flash Point	Pyrophoric	160°F minimum
Boiling Point		468°F to 510°F

BORON FUELS (CONT.)

Toxicity

The products of complete combustion of HEF-3 or Hi Cal-III are water and boric acid, which is a very mild acid (eye wash). Little, if any, trouble is expected from this source with the possible exception of some damage to vegetation around ground run-up areas.

The unburned fuel is highly toxic when inhaled or absorbed through the skin or swallowed. Since these fuels have a strong distinct odor, there is no excuse for trained personnel to inhale sufficient quantities to cause a health hazard. Absorption through the skin comes in much the same category as inhalation as it can be easily detected and can be washed off before any damage is done. Swallowing several c.c. of HEF-3 is entirely possible, but extremely improbable by trained personnel.

The Callery Company, producers of Hi Cal, have had lost-time accidents due to boron exposure, but in all cases these were not caused by the final product (Hi Cal-III) but by one or more of the more active agents used in processing such as diborane, boronhydrides, etc.

Material Compatibility

There has been enough work done on the material compatibility program to prove that the most of the materials proposed for the A-11 airplane are uneffected by HEF-3 or Hi Cal-III. The few questionable ones are non-structural so there will be no weight or performance compromises to be made on the airplane if substitutes are made.

BORON FUELS

Material Compatibility (Cont.)

As the A-11 airplane structure is predominately titanium, which is inert to boron fuels, this will reduce the amount of testing to a few metals.

There is a mild reaction between boron fuels and aluminum which may or may not be tolerable for airplane components; future test will verify this. The amount of aluminum which could be used on the A-11 airplane fuel system is limited to tank baffles and valve bodies for which there are several substitutes.

Steel, copper, stainless and most other structural metals are satisfactory for use in boron fuels. Rubber and most plastic materials must be avoided as they deteriorate rapidly in HEF. In most cases, these materials must be replaced with Teflon, Kel. F., Vitron, or one of the other fluorinated materials.

There are several currently active programs for development of sealant materials being carried out for WADC. The results are promising; however, it is anticipated that further testing and development will be required.

Boron fuels may be used with hydrocarbons such as the JP fuels and lubricating oils, provided the latter are free of water which hydrolizes

BOROON FUELS

Material Compatibility (Cont.)

the fuel and forms a boric acid deposit which could clog fuel lines, etc.

Chlorinated material such as carbon tetrachlorid must not be used around or with HEF as the reaction compounds are explosive and shock sensitive. Some of the other halogen compounds must likewise be avoided for the same reason.

Fuel Handling

The new boron fuels HEF-3 and Hi Cal-III can be handled safely if a few safety precautions are taken. The fuel should be kept under an inert atmosphere such as nitrogen gas. Spills should be avoided even though the fuel is not pyrophoric. If fuel is spilled, it should be washed away with water or burned to avoid the vapors from being inhaled. If it is impractical to burn the fuel, it may be hydrolized with a water-methanol mixture (50-50).

Personnel handling quantities of boron fuels should wear protective clothing such as rubber gloves and sleeves, gas masks and safety goggles. The most important thing, however, is adequate training and good common sense.

Before a container is fueled, it should be thoroughly cleaned and dried and purged with a dry inert gas such as nitrogen. The purging can

BORON FUELS

Fuel Handling (Cont.)

best be accomplished by pressure purging; i.e., filling the container with dry N_2 several times to its permissible operating pressure and bleeding to ambient. If venting is required when fueling the container, the vapor should be disposed of by burning or bubbling through a water-methanol trap.

THERMODYNAMICS

A. Power Plant System

I. Engine Selection

Early in the Archangel series of airplanes, a comparison of the Pratt and Whitney J-58 engine and the General Electric J-93 engine was made. The performance comparison on a specific weight and specific thrust basis were almost identical up to about 75,000' altitude. Above that height the J-58 engine was better than the J-93.

Since maximum altitude was a major criterion, the engine having the best thrust/weight ratio could achieve the highest altitude. A preliminary analysis showed that approximately 3,000 feet greater altitude could be achieved with the J-58 engine. In addition the hardware development of the J-58 engine is approximately a year ahead of the J-93 engine. Consequently, the J-58 engine was selected as the A-11 airplane power plant.

II. Engine Performance

The installed J-58 engine thrust and fuel flows at maximum power are presented in Figure 1. The data are based on the use of JP-150 in the primary burner and HEF in the afterburner. The performances are based on the inlet recoveries shown in Figure 4. The data are for a climb speed of 400 knots E.A.S. up to 74,000 feet and at M = 3.2 above 74,000 feet. Figure 2 shows the variation of S.F.C.

THERMODYNAMICS (Cont.)

A. Power Plant System (Cont.)

II. Engine Performance (Cont.)

with afterburner power at M = 3.2. The effect of using HEF in the afterburner only results in a decrease in overall SFC of 12% over an all JP-150 system. This factor is substantially less than 28% theoretical gain and is due primarily to the present uncertainty of the condensation of boron-oxide in the nozzle and secondarily to the difference of the molecular weights of the combustion products. It is believed that with development, a greater factor will be achieved.

An engine weight of 5,950 lbs. was used to allow for the large ejector diameter, for the structure required to use the engine up to M = 3.2, 100,000 feet, as well as the dual fuel compatibility of the afterburner.

III. Induction System Performance

A two-dimensional external-internal compression inlet was selected for the induction system of the A-11 airplane. A schematic diagram of this inlet type is shown in Figure 3. This inlet was chosen since its layout fits the general layout of the airplane without sacrificing performance. A three dimensional inlet would provide slightly greater recovery, however, it would be harder to control. The final selection of the inlet would be made after an intensive wind tunnel program.

THERMODYNAMICS (Cont.)

A. Power Plant System (Cont.)

III. Induction System Performance (Cont.)

NASA has recently shown that at Mach numbers greater than 2.5, the inlet recovery is almost independent of inlet type. The pressure recovery within ± 3% is dependent on the amount of compression surface boundary layer removed. Table 1 summarizes the effect of boundary layer removal.

TABLE 1

Total Head Recovery, %	B.L. Bleed Req'd., % of Inlet Captured Flow
90	30
85	20
80	10
75	5

Although the high pressure recovery is attractive, the utilization and/or efficient disposal of above 10% of the inlet captured flow at high Mach number is extremely difficult without incurring large quantities of drag. For example, dumping 20% of flow in engine secondary nozzle results in an increase of approximately 8% in SFC.

Figure 4 shows the inlet pressure recovery assumed in the engine analysis. Also, shown are test data obtained in wind tunnel tests conducted both by this contractor in its supersonic transport studies and by NASA at M = 3.0. Also shown for comparison is the new proposed A.I.A. standard recovery curve.

THERMODYNAMICS (Cont.)

A. Power Plant System (Cont.)

III. Induction System Performance (Cont.)

Another factor in inlet selection is inlet drag. This drag is composed of the external drag (cowl pressure and friction drag) and the inlet spillage drag. With the common external compression inlet, the cowl pressure drag that accompanies the large compression surface angles, as well as the spillage drag at off-design conditions make the simple inlet impractical at high Mach numbers. With a mixed variable inlet, a low angle external cowl surface is possible minimizing the cowl pressure drag, and the spillage drag is supersonic which is considerably lower than subsonic spillage drag associated with spillage behind a normal shock.

The engine location was determined by the airplane c.g. requirements. An under-wing inlet was selected since this type of inlet would be insensitive to angle of attack. It was then necessary to determine inlet location, that is, ahead of or behind the wing shock.

Locating the inlet ahead of the wing shock has the following advantages:

a) Requires no boundary layer diverter.
b) Utilizes the top surface of the inlet for additional wing area.
c) Allow for a long subsonic diffuser thereby improving pressure distribution.

THERMODYNAMICS (Cont.)

A. Power Plant System (Cont.)

III. Induction System Performance (Cont.)

On the other hand locating the inlet behind the shock:

a) Lowers the inlet Mach number thereby making it possible to achieve a higher recovery and lowering the inlet capture area.

b) Reduces the inlet momentum or ram drag of the engine thereby increasing net thrust, since the momentum decrement has been charged to the wing pressure drag. (No allowance was made for this in the performance).

c) Reduces the inlet capture area thus reducing the inlet-engine matching problem and associated spillage drag.

The principal disadvantage of this latter location is the requirement of a boundary layer diverter and its attendant drag. This contractor is currently running a full scale diverter wind tunnel test at the NASA Lewis Research Center to verify the drag data previously obtained with scale model diverters. Boundary layer diverter drag has been included in the performance.

In addition to the aerodynamic factors the latter location is shorter and therefore lighter. Consequently, the behind-the-wing shock under-wing inlet was initially selected subject to the wind tunnel program.

THERMODYNAMICS (Cont.)

A. Power Plant System (Cont.)

VI. Exhaust System

The Pratt and Whitney rectangular ejector is proposed for the A-11 exhaust system. The engine manufacturer's test data show that there is no difference in performance between a rectangular and circular ejector nozzle. The use of a rectangular ejector minimizes the base drag problem and allows greater ground clearance angle. The inlet compression surface boundary layer air, approximately 7% at cruise, will be ducted aft to act as the secondary airflow required by the ejector. At off-design conditions, a portion of the by-pass air required to minimize spillage drag will be dumped in the secondary nozzle. The quantity will have to be determined in wind tunnel tests.

THERMODYNAMICS (Cont.)

B. Aerodynamic Heat Transfer

I. Structural Temperatures

A steady state heat transfer analysis was made of a typical wing chord. Figure 6 shows the temperature distribution on the upper and lower surface of the wing. The data show that the average upper surface will be approximately 425° F and the average lower surface temperature will be approximately 475° F. The difference in temperature between the upper and lower surface is due to the compression resulting from the wing operating at 7° angle of attack. The heat transfer analysis was based on the Van Driest method which has been checked experimentally by NASA in free flight tests.

The temperature on the fuselage will vary from 400° F to 500° F. The minimum temperature will occur on the bottom surface with maximum occurring at the 10 and 2 o'clock positions due to effects of boundary layer crossflow at angle of attack. A temperature of 475° F will occur at the wing-fuselage intersection as well as at the intersection of any protuberances such as antenna masts. The protuberance temperature itself can be decreased by sweep. These data are based on calculation methods checked experimentally on the X-15 configuration.

The external windshield surface temperatures will vary from 770° F at the stagnation point to an average of 450° F over most of the

THERMODYNAMICS (Cont.)

B. Aerodynamic Heat Transfer (Cont.)

I. Structural Temperatures (Cont.)

canopy surface.

II. Fuel System

The engine manufacturer requirements as well as the fuel temperature never exceed 300° F for either JP-150 or HEF fuel.

The results of a preliminary investigation show that through judicious scheduling of fuel to regions which are less susceptible to rpaid transient temperature rise, an uninsulated fuel tank system can be used for the A-11 airplane.

Integral fuel tanks, both for the fuselage and wing, have been designed for the airplane. At this time, a detailed analysis has been made for the wing integral tanks and is presented below. No analysis, as yet, has been made for fuselage integral tanks; however, preliminary spot checks as well as conclusions drawn from a bag type fuselage tank system design, discussed below, show that the fuel temperature limitation can be adequately met. The bag type fuselage tank design study made represents a feasible tank design configuration in the event the sealing material problem associated with integral tanks fails to be resolved.

A preliminary heat transfer was made on typical fuel system

THERMODYNAMICS (Cont.)

B. Aerodynamic Heat Transfer (Cont.)

II. Fuel System (Cont.)

configuration. The study was divided into wing fuel tanks and fuselage fuel tanks. The wing fuel tanks were assumed to be integral and that the wing fuel would be used either during climb or the initial portion of the cruise. The fuselage fuel tanks were assumed to be in bags and to be used only during the cruise portion of flight. No insulation was used in either the wing or fuselage tanks. It is assumed that the wing tanks will be kept at 5 psi differential and fuselage tanks at 8 psi differential.

Figure 6 shows the time-temperature history of the wing integral tanks. The curve for use of wing fuel for climb shows that at the beginning of cruise the fuel temperature has risen 120° F. The temperature reaches the 300° F limit, assuming an initial 60° F temperature, after 25 minutes or 20% of the total flight. The rapid temperature rise experienced in the tanks are due principally to the tanks being empty. Also, shown in Figure 6 is condition if wing fuel is not used until beginning of cruise. Results show that 40 minutes are available before 300° F is reached assuming initial fuel temperature is 60° F. This time is more than adequate to use up the wing fuel.

Figure 7 presents the time-temperature history of the fuselage tanks. It should be noted that maximum fuel temperature rise is 52° F

THERMODYNAMICS (Cont.)

B. Aerodynamic Heat Transfer (Cont.)

II. Fuel System (Cont.)

where the vapor at top of tank rises 300° F.

It is emphasized that this preliminary study should be used to give an order of magnitude since results can vary if fuel quantities and schedules or tank configuration are different from those assumed.

The study also indicates that fuel can be routed from the fuselage to the wing tanks, during the entire mission if necessary, without exceeding the limit temperature. It is intended at a later date to use IBM 704 Thermal Analyzer to obtain a more accurate analysis and thereby determine the optimum fuel routing compatible with c.g. requirements as well as the actual tank configuration.

Another fuel problem other than material compatibility is the temperature effects on the residual fuel. It is presently planned to purge the tanks completely upon emptying the tanks so as to insure no residual fuel, since any residual fuel will result in tank coking.